The Influence of Variation of Temperature upon Nervous Conductivity, studied by the Galvanometric Method.

A Dissertation submitted to
The Board of University Studies of
The Johns Hopkins University
for the degree of Doctor of Philosophy
by

J. W. Herrick

Baltimore Md.
1900

Contents.

Introduction

In general each tissue has its upper and its lower lethal temperature, and its thermal optimum or optima.

The nerve is quite sensitive to changes in temperature, as we may observe in studying its terminal organ or the galvanometric response.

By means of a certain degree of heating or cooling we are enabled to block the nerve impulse, without necessarily killing the nerve.

The velocity with which the nerve impulse is propagated depends upon the temperature of the nerve, being greater at higher temperatures.

The power to respond to external stimuli is also influenced by the temperature: a

warmed nerve being more capable of replying to a short stimulus, a cooled nerve needing a longer stimulus.

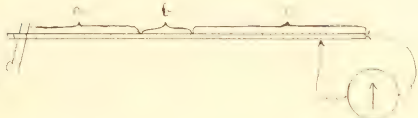
Conductivity, or the power to respond to its own internal stimulus, is affected by the temperature; for if the nerve impulse passes through a heated area it is increased; if through a cooled area it is diminished. That the nerve impulse, when it passes through a heated area, is increased has been observed, so far as I know, only in the case where the end effects of the stimulus in the organ supplied by the nerve were observed. As is well known, we have two methods of studying nervous activity; we can take the organ supplied by the nerve, most conveniently the muscle, and observe its response; or we can employ the galvanometer or electrometer which

indicate the difference of electric potential set up between different points of the nerve when a nerve impulse passes. With the galvanometer we observe upon stimulation of the nerve the so called negative variation or action current.

Will this negative variation also increase when the nerve impulse passes through a warmed region?

Statement of the Problem: History

The problem may be stated schematically as follows:-



If a b c be the nerve, and the temperature of a and c be maintained constant while the temperature of b is raised, will the action current observed in the galvanometer be increased? Under similar conditions the muscle response upon indirect stimulation is augmented. If the galvanometer takes the place of the muscle, will its deflections increase as the muscle contractions increase?

Bernstein (1) observed that, when he raised the temperature of the nerve between the

stimulating electrodes and the muscle, the muscular response increased. He called attention to the fact that raising the temperature of the nerve at the point stimulated would increase the electrical conductivity, an observation which evidently escaped Gotch and Macdonald (2).

Howell (3) observed an increased vasoconstriction upon allowing the nerve impulse to pass through an area heated to 42° - 47° C. Howell's, as well as Bernstein's, observations were made in the case of the mammal.

Hirshberg (4) made observations upon frogs nerve. He found that, warming a nerve locally from 15° to 30° C and stimulating in the warmed region, the secondary coil had to be shoved farther out from the primary for a minimal contraction.

the irritability was increased. But if he then stimulated above the warmed area, thus permitting the impulse to pass through a stretch of nerve of higher temperature, the coil had to take its original position for minimal contractions, i.e. there was no change as far as the conductivity of the nerve was concerned. This negative result might easily be explained by the comparatively low temperature 20° C. selected.

Verweg 30, in his experiments upon the effect of thermal changes as to the duration of the monophasic action current, observed that, on passing the nerve impulse through a cooled area, or stimulating in a cooled area, there was a decrease in the amount i.e. size of the action current, although there was no change in its duration. In these experiments he also warmed the nerve

between the point stimulated and the portion led off to the galvanometer, but he does not compare the action current so obtained with that observed without warming, nor does he give the exact temperatures employed.

Boruttau (6) studied the effect of passing the nerve impulse through a cold area, and found that the negative variation persisted after the muscular response had disappeared. He also verified and amplified Verwey's work, finding the duration of the diphasic as well as that of the monophasic action current dependent only upon the temperature of the stretch of nerve included in the galvanometer circuit, not upon the stretch outside that circuit. He very aptly calls attention to the following

If in our figure a b and c are all at the same temperature, say, 20°C, then the stimulus, started in a at the exciting electrodes and passing through b, will arrive after a certain time at the proximal electrode, causing a monophasic action current.

If now the temperature of a and c remain unchanged, while b is cooled down to, say, 5°C, we shall notice:–

1) that the negative wave reaches the proximal electrode later than in the first case, due to the retardation in b;

2) that the action current is less intense, i.e. of less amplitude;

3) that the duration is unchanged, because in order to affect it, the temperature of the led-off stretch itself must be changed.

If instead of cooling b, as Boruttau did, we should warm this stretch of nerve, we should expect:

1) the arrival of the wave of negativity at the proximal electrode to occur after a shorter interval than when the nerve was throughout at 20°C;

2) a greater intensity of action current;

3) no change in the duration of the monophasic action current.

Waller (7), in studying the effect of variations of temperature upon the electrotonic currents A and K, observed that the negative variation is temporarily abolished at about 40°C; a positive gives place to a negative variation in consequence of a raised temperature to 40°C

Division of Experiments.

The experiments composing this investigation may be best divided into two series.

The experiments of the 1st. series were carried out in the spring of 1899, and fall under two heads: those relating to conductivity; those relating to irritability. In these experiments there was no increase in the action current observed whether the stretch b or the stimulated stretch was heated. However, in the case of the conductivity experiments, because of the small action currents obtained with the nearly maximal stimulus employed, the results were not satisfactory. In addition to this a new form of non-polarizable electrode had been

used which had not proved to be of equal rank with the usual form.

I wished to check my results, so the conductivity experiments – as these were of first importance – were continued.

These make up therefore the experiments of the 2nd series, and were performed during the present scholastic year, 1899-1900. They may be classed under three groups: 1. Stimulation was by means of induced currents; 2. Condenser discharge was used as stimulus; 3. The negative variation was obtained by reflex stimulation. In all these experiments the galvanometric response was the one observed.

As a check upon the galvanometric work I performed a number of experiments using the muscle as my indicator, but

these experiments are not reported separately; if reported at all, they are incorporated with those in which the galvanometric response was observed.

Experiments of 1st Series
Apparatus and method

The first method tried was that used by Gotch and Macdonald[x], viz: allowing the nerve to lie across a thin walled glass tube, through which water of various temperatures could be passed. But, as it was found that the nerve under these conditions would readily dry, this method was given up and another procedure was adopted. The nerve at one place was allowed to dip into a small vessel of normal salt solution; this bath was supplied by Mariotte's bottles so that the level of the bath remained constant. A number of experiments were obtained by this method, but it proved to be awkward and hard to control; in addition

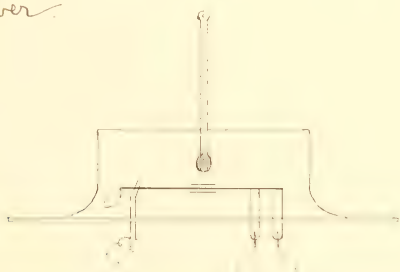
[x] l.c. p. 252

normal salt solution of 35° – 40°C cannot be regarded as an indifferent fluid.

The method finally adopted as the one most satisfactory was the threading of the nerve through a tunnel, water being circulated about the tunnel. The tunnel was about 10 m.m. long consisting of a small German silver tube let through a larger tube of the same material, through which water flowed from bottles placed upon an elevated stand. The larger tube was Λ shaped, the smaller tube piercing it at the angle. This form of temperature tube is one used by Prof. Howell. The inside of the tunnel was at first coated with paraffin, then a thin walled small glass tube was inserted which just fitted the lesser metallic tube, thus making a glass-walled

tunnel. This was of advantage in that the nerve did not come into direct contact with the metal.

A small moist chamber was used consisting of the bottom of a specimen dish, which was inverted and rested upon an ebonite base. Through the ebonite base projected the angle of the Λ shaped tube containing the tunnel. A hole was drilled into the bottom of the dish through which, when the dish was turned upside down, a thermometer was inserted to determine the temperature of the chamber.

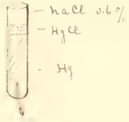


The non-polarizable electrodes were also inserted through the base into the chamber. They deserve a word of mention, for they differ from the usual type of non-polarizable electrodes. These electrodes were patterned after those recommended by Ostwald *. At Dr. Howell's suggestion they were used in this first series of experiments.

The substances composing the electrodes are the following: mercury; calomel; NaCl 0.6%. They are best made by fusing a platinum wire into a glass tube of convenient size; thoroughly cleaning the tube and the piece of platinum inside by boiling in a solution of bichromate of potassium in dilute sulphuric acid; washing with tap water, then distilled water, and finally drying by alcohol and ether. When the components are put in

* This type of electrode was described by Howell at the meeting of Amer. Physiol. Soc. New York, 1899

The tube should be filled to within 3 or 4 m.m. of the top with pure mercury, then a layer of calomel is added. The addition of the latter can be most conveniently effected by having the calomel under normal salt solution in a bottle, and taking it up along with some salt solution by a pipette.



All the components of the electrode should be pure, and the tube should be kept erect, precautions being observed against shaking the mercury about.

If these electrodes are properly made, they are quite isoelectric; however, from a few experiments made in the spring of '99, they did not seem to be as sim-

polarizable as the amalgamated zinc--zinc sulphate electrodes of Du Bois Reymond.

These electrodes have the advantage that they can be used for a long time without having to be remade, provided evaporation is avoided. I have it recorded that one pair was used 20 days during which time they remained quite isoelectric; in this instance, however, the calomel and normal salt solution were renewed.

A quite recent communication from Oker-Blom describes another style of the same electrode. I think the form used in this laboratory is the more convenient.

As stimulating electrodes platinum points were employed. They were connected with the secondary coil of an ordinary inductorium of the horizontal type. The primary coil was fed by an Edison-Lalande

cell, the Helmholtz modification being used. In this series of experiments the iron core remained within the primary coil, as it was fixed.

With regard to the stimulus employed in these experiments of the 1st series (which was throughout faradic), it must be stated that the strength of the stimulus expressed in secondary coil distance is not given. In the conductivity experiments a slightly sub maximal stimulus was obtained, and this stimulus was not changed during the experiment. In the irritability experiments a maximal stimulus was employed.*

The nerve used was the frog's sciatic, either fresh, or after having been kept over

* For description of the galvanometer see 2nd series p. 39

night in a cool place.

Having threaded the nerve through the tunnel and arranged it upon the two pairs of electrodes, the stimulus was selected, and then changes in the temperature of the stretch b or the stimulated stretch were begun. The flow of the water through the tube surrounding the tunnel was regulated by pinch-cocks, and by mixing the cold and hot supplies in proper proportions, the desired temperature could be reached.

The raising of the temperature of the stimulated stretch was secured by placing two little coils of platinum wire in the tunnel; these served as stimulating electrodes.

No precautions were taken against a rise in the electric conductivity of the stim

ulated stretch when it was heated, because there was no increase in the action current even as things were.

The stimulated and led off stretches were widely separated.

In order to prevent drying, a small piece of sponge was fastened with sealing-wax to the inside of the moist chamber. This chamber was so small that its temperature could be kept fairly constant by placing a small crucible on top of it, the crucible being filled with warm water when the temperature of the water around the tunnel fell, with ice water when the temperature rose; thus by putting on and taking off the crucible the temperature of the chamber was kept constant. By means of vaseline around the base the chamber was rendered air-tight.

Results of Conductivity Experiments

The result of these experiments may be briefly stated as follows;

When the stretch b was warmed there was no increase in the action current up to the lethal — about 47°C. — temperature. As this temperature was approached the action current decreased, disappearing even at a temperature of 42°.

Cooling the stretch b sufficiently caused a considerable decrease in the action current — a temperature of 0°C producing a marked effect, but still in general not blocking out the negative variation. It was only with very low temperatures, -2° to -7°C that the negative variation disappeared (the stimulus being nearly, if not quite maximal). Of course at this low tem-

perature the nerve will freeze, if it is exposed too long; such low temperatures have a deleterious effect.

If these high and low temperatures at which the negative variation disappears were not maintained too long, the action current reappeared upon removing the block, in some instances in full strength.

As to the temperatures high and low at which the action current resulting from a maximal stimulus begins to decrease, if the nerve impulse has to pass through a nerve stretch of such temperature, it is hard to make any definite statement; for the duration of the exposure to the change in temperature is an important factor. In general the nearer the temperature lies to the lethal, the shorter has to be the

posure in order to cause a decrease in the action current, which is of course what would be à priori expected. Temperatures between 35° and 10°–8°C seem to be indifferent while above 35°C and below 8°C there is a decrease to a complete blocking out at 47° and −2°– −7°C respectively.

The accepted conductivity experiments number 23 of which the following may serve as examples

The headings of the columns are as follows:

No = number of the observation

D - demarcation current

a - action "

Temp. = temperature of the stretch b

The time of beginning is given and there after the intervals between the observations in minutes.

Experiment no 21

Nerve kept 6 hrs. Loop of nerve dipped into bath of normal salt solution between stimulati[illegible] and lead-off stretches

no	D	a	Temp.	Time	Remarks	no	D	a	Temp.	Time	Remarks
1	51	6.9	25°	—		17	33	6.2	35	4	
2	50	7.0	"	—		18	-		12	[illegible]	
3	—	—	9	4-41		19	30	7.0	11	4	
4	42	7.5	8	3		20	25	6.2	"	5	
5	43	6.1	39	3½	[illegible]	21	24	"	12	4	
6	—	—	11	2½		22	40	8.5	"	4	Fresh scissors' section
7	44	7.3	9	2		23	42	8.8	"	[illegible]	
8	—		24	2		24	41	8.2	"	4	
9	37	6.8	25	2		25	40	8.3	"	2	
10	39	7.0	"	2		26	"	[illegible].7	"	1½	
11	—	—	12	2		27	-	—	30	2½	
12	35	7.1	10	3		28	45	6.9	33	[illegible]	
13	33	7.6	"	2		29	48	7.2	"	3	
14	—	—	34	4		30	49	7.4	"	3	
15	36	5.9	36	3½		31	-		14	5	
16	38	6.3	[illegible]	2½		32	42	7.7	"	2	

no	D	a	Temp.	Time	Remarks
33	40	8.0	14	3	
34	38	8.1	"	2	
35	—		29	2	
36	38	7.5	30	2½	Temp. of moist chamber varied from 22-25°
37	41	7.2	"	1½	

Experiment no 26

nerve kept 24 hrs; threaded through tunnel.

no	D	a	Temp.	Time	Remarks	no	D	a	Temp.	Time	Remarks
1	57	8.2	—			11	—		45	1	
2	54	11.0				12	—	8.2	47	½	
3	61	11.5				13		3.8	49	1	
4	29	9.5	25°	h m 10.47	[illegible] moist [illegible]	14		1.5	·	¾	
5	—		45	1½	Temp. moist chamber, 25°	15		0.7	--	¼	
6	55	0.5	48	1		16		0.1		[illegible]	
7	—	—	23	½		17	—	0.0	48	[illegible]	
8	59	8.5	"	1½		18	—	5.1	24	1	
9	55	8.5	25	3		19	5.5	5.2	23	4	Temp. moist chamber, 26°
10	55	8.2	"	5							

Experiment no 28

[illegible]

[illegible]	D	a	[illegible]	[illegible]	[illegible]
1	33	11.0	—	—	
2	31	11.0	—	h. m. 11-27.	
3	—	—	-5°	$\frac{1}{2}$	
4	—	7.0	—	$\frac{3}{4}$	
5	—	3.2	−6	$\frac{1}{2}$	
6	—	1.8	"	$\frac{1}{2}$	
7	—	1.0	—	$\frac{1}{[illegible]}$	
8	—	0.0	—	$\frac{3}{4}$	
9	—	11.5	20	$\frac{3}{4}$	
14	31	8.7		h. m. 12 [illegible]	
15	"	8.8	24°	3	
16	—		38	1	
17	30	[illegible].1	37	$1\frac{1}{4}$	
18	31	8.2	"	$2\frac{1}{4}$	
19	—		24	$\frac{3}{4}$	
20	—	8.3	24	$1\frac{1}{4}$	
21	31	8.7	"	$2\frac{1}{2}$	
22	—	—	4	1	
23	28	7.9	3	$2\frac{1}{4}$	
27	20	5.0	3	7	
28	"	7.8	24	$1\frac{3}{4}$	Temp. [illegible] 25.2[illegible]

Results of Irritability Experiments.

When the stimulated stretch was heated there was no increase of the action current produced by a maximal stimulus. Even as low a temperature as 29°C. seemed in one experiment unfavorable. At 45° or a few degrees above this temperature the stimulated area lost its power to respond to the external stimulus.

If cooling was employed, the cooled stretch still remained irritable to a maximal stimulus (functionally maximal) at 0°C., though the galvanometric response was considerably lessened; at -2° to -5° the response was about halved. In one experiment the temperature had to be lowered to -10°C to cut out the action current.

The temperature limits within which

there was no effect we may put it 25°·30° [illegible] to 10°C.

The accepted experiments numbered 15 of which the following are examples.

Experiment no. 4

Nerve kept 3½ hours; the stimulated stretch lay in the tunnel

Temp. = temperature of the stimulated stretch

No	D	a	Temp.	Time	Remarks	No	D	a	Temp.	Time	Remarks
1	53	4.5	—	h. m. 3.43		14	—		0	1½	
4	–	6.0	–	1½	Time recorded	15	–	4.0	1	1½	
5	46	6.0	21	2		16		–	2	3½	
6			–1	2		17	–	4.5	3	1½	
7	–	3.3	–2	¾		18			4	2¼	
8	–	2.9	"	1¼		19	34	5.3	5	1¾	
9	–	"	"	1¼		20			6	1¼	
10	–	2.8	"	¾		21	–		7	¾	
11	–	2.9	"	1½		22		6.1	8	1	
12	–	–	20	1		23	–	–	10	1	
13	–	6.4	"	2		24	–	6.4	"	1½	

					Remarks
25			14	1	
26	-	6.6	15	1 [illegible]	
27	-	-	11	$2\frac{1}{2}$	
28	22	6.3	12	$1\frac{1}{4}$	
29	--	-	16	$1\frac{1}{4}$	
30	-	6.6	19	1	
31	—	-	20	$\frac{1}{2}$	
32	-	7.0	21	$1\frac{3}{4}$	
33	--		23	$3\frac{3}{4}$	
34	-	6.3	26	1	
35		-	28	$1\frac{1}{4}$	
36	-	7.0	29	$1\frac{1}{4}$	
37	-	6.0	31	2	
38	-	6.7	33	$2\frac{1}{4}$	
39	-		36	1	
40	-	6.0	"	$\frac{3}{4}$	
41	31	6.7	38	$2\frac{1}{2}$	
42	-	5.8	42	2	Temp. moist chamber. 23-24°
43		2.2	43	2	
44	-	5.5	21	7	nerve not dried

Experiment no. 41

nerve kept in [illegible], stimulated [illegible]

No	D	a	Temp.	Time	Remarks
1	42	6.7	18°	1 3/4	
2	–	6.1	"	2 1/4	[illegible]
3	–	7.1	19	[illegible]	
4	–	7.0	21	2 1/4	
5	—	6.4	23	2 3/4	
6	—	–	25	3/4	
7	—	6.8	26	1 1/4	
8	35	5.4	29	2	
9	—	—	31	1 1/4	
10	–	5.1	"	1	
11	–	4.8	33	2	
12	–	5.0	35	1 3/4	
13	–	–	37	1/2	
14	—	4.0	38	1 1/2	
15	—	1.7	39	2 3/4	
16	–	0.5	40	1 1/4	
17	–	–	20	3/4	
18	–	4.4	21	1	
19	33	4.3	"	3 3/4	
20	50	5.2	"	3 3/4	Temp. moist chamber 20-22°
21	75	6.0	—	12 3/4	at 20 fresh section [illegible]
22	–	0.0	50	2 3/4	Exposure at 50° 1 min.
23	–	3.4	23	1	nerve not dried

Experiment No. 48

Nerve fresh; stimulated stretch in tunnel

No.	D	a	Temp.	Time	Remarks
1	60	5.0	–	[illegible]	
.					
6	45	3.9	–	24	[illegible]
7	–	7.2	21°	$2\frac{3}{4}$	
[illegible]	-	7.0	-4	$1\frac{1}{2}$	
[illegible]	–	2.6	-5	1	
10	–	2.1	"	1	
11	–	1.9	"	$\frac{3}{4}$	
12	–	1.7	-3	1	
13	–	1.6	-6	1	
14	–	1.4	-7	1	
15	–	1.2	"	$\frac{3}{4}$	
16	–	1.5	-7	$1\frac{1}{4}$	
17	–	–	-10	$\frac{1}{4}$	
18	–	1.1	"	[illegible]	

No.	D	a	Temp.	Time	Remarks
19	–	0.7	10	$\frac{1}{2}$	
20		0.3	"	$\frac{3}{4}$	
21	–	0.0	"	$\frac{3}{4}$	
22	–	0.0	14	1	
23	-	0.3	"	1	
24	33	1.7	22	2	
26	–	2.0	27	[illegible]	[illegible]

Experiments of 2nd Series.

The results of the experiments of the spring of 1899 were entirely negative, as to any increase in the action current when the nerve impulse passes through a warmed region. But it must be remembered that in these experiments the stimulus was almost if not quite maximal — such a stimulus having been chosen in order to get a large action current.

In the experiments of the following fall care was taken to make the stimulus certainly submaximal. and, as the experiments progressed, to make the stimulus minimal.

In this series a diversity of stimuli was employed including induced cur-

rents, condenser discharge, and reflex stimulation.

Gotch and Macdonald* have shown that, as far as irritability is concerned the temperature and the kind of stimulus stand in relation. Warming the stimulated point of the nerve increases the muscular response, cooling decreases it, if the stimulus be the induced current. For the condenser discharge ("prolonged" pattern) cooling increases, warming decreases the contraction; the same is also true for stimulation by means of galvanic and sinusoidal currents .005" or longer in duration.

It was therefore of interest to see whether the nerve showed any difference in its conduction of a stimulus through an area, the temperature of which was varied,

* l.c. p. 282

according as the internal stimulus was started by an induced current or a condenser discharge.

The explanation for the selection of the reflex stimulation will be given in due place.

Before passing to the description of apparatus used in the 2nd series of experiments, which differed considerably from that of the 1st series, it may be well to call attention to a few sources of error, and point out the precautions taken.

In galvanometric experiments where temperature is one of the factors care must be taken to avoid unequal heating of the electrodes which lead to the galvanometer, otherwise hydrothermoelectric currents will arise and be a source of error, as pointed out by Hermann 11. It will be shown

in what follows that this error was guard-ed against.

If we heat the stretch b we should be provably justified in assuming that the change in temperature would remain very well localized in b, owing to the poor conductivity of the nerve tissue. To be quite sure I have in the following experiments, for the most part at least, provided against such possible conduction.

Another probable source of error is namely: the heating of the stretch b might itself act as a stimulus and produce a negative variation; however, this would be a small error if actually occurring, for, as Grützner (2) has shown, the negative variation following upon stimulating by heat is excessively small.

A source of error which has caused me

much trouble was the drying out of the nerve in the region where the temperature was raised. Unless the nerve is very large, the evaporation that goes on immediately around the stretch b is sufficient to dry it, if special precautions are not taken, such as frequent moistening or the enclosing of the stretch in a narrow tube. In addition to the injury arising from the drying, there is also the possibility of increased irritability in the stretch b, since a certain degree of evaporation heightens the irritability, as is well known.

Errors common to all galvanometric experiments are such as arise from unipolar stimulus and electrotonic currents. The first was excluded by using strengths of current incapable of producing the pho-

nomenon; even with one pole of the inductorium put out of circuit I have been unable to get unipolar effects with the maximal strength of current employed. Electrotonic currents were guarded against according to Bernstein's (13) recommendation. I have uniformly removed the stimulated stretch at a distance from the led off stretch — almost to the extent allowed by the length of the nerve; have made the distance between stimulating electrodes very small, about 2 m.m.; and have removed the iron core of the primary coil, employing at the same time Helmholtz's modification to equalize the makes and breaks as much as possible.

1. Stimulation by induced currents

Apparatus

The galvanometer employed was a high sensibility Rowland D'Arsonval type. One volt through 940 megohms produces a deflection of one millimeter at one meter distance, i.e. one millimeter scale division = about 10^{-9} ampère. The resistance of this instrument is 2780 ohms. The instrument is independent of the earth's field and can consequently be placed in any desired vertical plane. It is provided with an adjustable scale, the deflections being read with a telescope. It is perfectly dead-beat, and the zero position is constant.

The laboratory in which these experiments were performed is situated quite

near an electric car line, but this factor was found to have no influence upon the galvanometer. I mention this, as I have read complaints from some observers who assert that their galvanometric work is very much interfered with by neighboring car lines. The D'Arsonval type of instrument has here a great advantage.

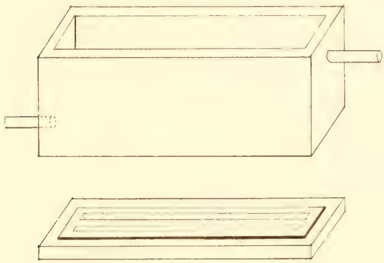
The induction coil used was the upright style made by Petzold. The secondary coil has 10,423 turns of wire. The instrument as delivered has no arrangement for the Helmholtz modification; this had to be added by the laboratory mechanic. The primary coil was fed by a storage cell having a potential difference of 2 volts between its poles. The cell was charged weekly.

using this cell with 3 to 5 ohms additional resistance in the circuit of the primary coil, the stimulus obtained from the secondary coil first became perceptible to the tip of the tongue at about 120 m.m. distance on the graduated scale.

A special moist chamber was constructed consisting essentially of a hollow parallelopipedon. It was closed in below by a heavy slate base, above by a glass top. The walls and top were double, through the space thus left water was circulated. This arrangement prevented any serious variations in the temperature of the moist chamber during the heating of the water bath. The following are the inside dimensions of this chamber: length = 11 cm,

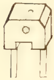
width = 3 cm, height = 3 cm. The space between the walls amounted to about 65 c.c.

The accompanying figure may serve to make clearer the arrangement.



This hollow walled tank, as we may call it, fitted into a corresponding [illegible] around the electrode base, indicated in the figure. The base had two slits in it which extended almost the full length of the moist chamber. These slits acted as guides for the stimulating electrodes, the

tube containing the tunnel, and the lead-off electrodes. The form of the tunnel tube is indicated in the diagram.



In order to make sure that the heating of the stretch to be confined to b, two similar tubes were also used, one on either side of the heater, through which passed water of the same temperature as that of the water supplying the tank. At first these three temperature tubes were separate, each having its own tunnel, but subsequently they had a common tunnel about 24 mm in length; around the middle third of the tunnel passed warm water, around the two end thirds tap water. Into the metallic tunnel was inserted a thin-walled glass tube, as in the experiments of 1st series.

In this manner the nerve lay in a chamber having a fairly constant temperature; the temperature of the electrode could be varied, but this change of temperature could not be conducted along the nerve, nor could the length of electrodes be unequally heated because of the water-bath temperature tube.

The stimulating electrodes were platinum points, which had an ebonite holder fitting into the two slits of the moist chamber base.

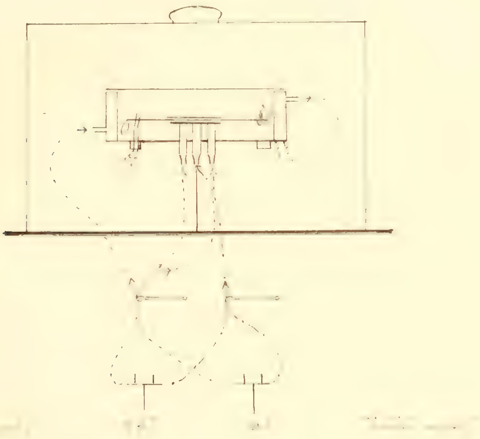
In this 2nd series instead of the Ostwald electrodes the amalgamated Zn-$ZnSO_4$ electrodes of Du Bois Reymond with plugs of kaolin were used. Great pains were taken in their manufacture, and only those were used that were fairly isoelectric ([illegible] .10 m.m.). They were held by

means of a special holder which fitted into the two slits of the base of the moist chamber. The two slits in the ebonite base of the chamber thus served as a sort of track along which the stimulating electrodes, the tubes containing the tunnel, and the non-polarizable lead-off electrodes could be displaced. Three small set screws made it possible to fix the electrodes and tubes firmly at any desired distance apart — a [illegible] [illegible] that proved very convenient.

The glass top closing in this nerve moist chamber was at first loosely laid on, then by means of vaseline it was made to fit very closely.

This nerve chamber was supported by a rod fixed into the base of a pretty large moist chamber. When the glass

top of the latter was put in place, the small chamber occupied the center of the space closed in by the large one.



The above figure indicates the arrangement schematically.

The laboratory is supplied with hot and cold water, and this supply was

instead of having bottles or tanks from which to draw the water. Such an arrangement relieves one of much trouble. Small hot and cold water pipes were installed to the table standing before the galvanometer; each pipe ended in a pair of stopcocks, so that two distinct streams of water could be obtained, the temperature of each of which could be varied independently of the other. One stream supplied the copper tank of the nerve chamber, and at the same time the two end tubes of the tunnel, while the other stream supplied the heater, i.e. the tube by means of which the stretch b was heated. The waste pipes are not indicated in the figure; they were led off to the sink.

By adjusting the hot and cold water

stopcocks properly the temperature of either stream could be nicely regulated. Thermometers, which had been compared with a standard were placed in the two streams and brought close together so that the readings could be easily taken. In general the temperature of the water flowing through the tank is given, as it was found that the temperature inside the chamber did not differ by more than 2 or 3 degrees from that of the water. In moderate weather tap water was used without adding any hot water.

When the tap water fell below 10 C hot water was added, but in some cases cold tap water was used; to the results obtained under such conditions especial attention will be called. In the protocols the temperatures are given with each

reading of the action current.

In a few of the experiments of this division a glass tube bent into a ∩-shape was used for raising the temperature of the stretch b. The limbs of the ∩ fitted into the slits in the base of the nerve chamber. Although the use of a glass tube in the former series did not seem to be successful, in the present series it was found to work very well. A wad of kaolin moistened with normal salt solution was sometimes placed about the stretch b of the nerve to prevent drying. In the protocols the use of the tunnel is understood unless otherwise stated.

Method and Results

The sciatic nerve of the frog was used throughout. The frogs, which were kept in the cellar of the laboratory, were for the most part of good size. The nerves were carefully removed, a piece of the spinal column usually being left in connection with the plexus. The full length of the nerve was used; the nerve being sectioned [illegible] near the knee.

As the action current was larger and more definite, i.e. the image of the scale came to a clean stop upon stimulation, after the nerve had lain over night in a cool place upon a piece of filter paper moistened with normal salt solution, such nerves were usually employed.

Such a nerve is designated "kept".

Either a scissor section or a thermal section was laid on the end of the nerve. The thermal section was made at first with a hot glass rod, later with a test tube containing scalding hot water. Since the latter method was most efficient, I shall describe it in some detail; attention to such points is very necessary in the technique of electrophysiology.

A long narrow test tube is procured, it is half filled with water, and the water brought to a boil; a portion of the end of the nerve is then brought into contact with the wall of the test tube which is held at an angle with its mouth away from the nerve, so that no hot water vapor will injure the rest

of the nerve. A few millimeters of the end of the nerve can thus be thoroughly cooked; a scissor section is made through the coagulated portion in case it is too long. With a millimeter or two of cooked tissue on the end of the nerve the demarcation current remains for a long time without decrease, e.g. in one experiment at the end of the first hour the demarcation current had fallen from 84 to 76 m.m., at the end of the second hour to [illegible] —. Care must of course be taken not to injure the rest of the nerve, and to make the thermal section clean, which is best done when the nerve is held perpendicular to the test tube.

Having prepared the non-polarizable electrodes and put them in position in the

nerve chamber, a ligature of silk thread was passed around the distal end of the nerve and tied to a thin piece of brass wire which was made like a needle by means of which I could thread the nerve through the tunnel. In order to accomplish this most easily the tank was removed from its base, which could be readily done. The nerve was threaded through the tunnel, laid over the stimulating electrodes and the lead-off electrodes, and then the portion of the nerve around which the ligature had been passed snipped off with scissors.

The proper precautions were taken for moisture by a liberal use of wet filter paper.

After the nerve was in position, the water supply was turned on and adjusted.

We may call the stream flowing through the tank and the two tubes on either side of the heater the "tank supply", the current passing through the heater the "heater supply". Both were quite copious so that the readings of the thermometers, indicated in the schema, represented very closely the temperature of the water passing around the tunnel.

Having set the temperature current (no compensation was used), the nerve was stimulated with various strengths of current; a stimulus of a certain intensity having been finally selected, the variations in the temperature of the stretch to were begun. These variations were for the most part sudden e.g. from 20° to 35 or 40° C, because of the rapidity with which the current

when exposed to higher temperatures.

The stimuli followed in some experiments at 2 minute, in others at 3 minute, in still others at 1 minute intervals.

In general at the end of the experiment the condition of the nerve, whether dried or not, was noted. If the nerve showed any signs of becoming stiff through evaporation this was recorded.

As to the temperatures of the stretch b a word should be said. It will be noticed in the reports of the experiments that the temperatures producing the same effects differ somewhat. This is due to the fact that the method varied a little; for, as already mentioned, the tunnel was at first divided into three parts which

to better prevent drying, were subsequently omitted. In this modified condition the two cooler streams tended to counteract the warm stream, necessitating an elevation of the temperature of the latter.

The following protocols or excerpts therefrom may serve as examples:

Exp. Mar. 19

[illegible] left [illegible] [illegible] [illegible] distance [illegible]

S.C. [illegible] [illegible] distance

No	D	A	Temp.	Time	Remarks
1	75	16.8	18°	h. m. 3-17	S.C. 100 mm.
2		13.9	19	3	" 120
3	75	"	20	3	
4		13.	35	3½	
5	–	12.1	36	3¾	
6	86	13	20	4	
7	–	"	37	3	
8	91	"	"	3	
9	–	12.3	38	3	
10	87	13.2	19	3	
11		11.0	39	3	
12	80	8.0	"	3	
13	–	10.3	18	3	
14	72	11.8	"	3	
15	–	12.8		4	
16	93	13.0	17	3½	
17	–	7.42	39	3½	
18	–	8.8	16	3	Temp. moist chamber 19°–22°
19	92	7.4	"	3	nerve not tried

[illegible] Nov. 17

Nerve quite fresh - large: end killed by hot glass rod.

[illegible]

No.	[illegible]	[illegible]	Temp.	Time	[illegible]	No.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	8[illegible]	[illegible].2	—	h. m. 11-27	S.C. 120 mm.	16	72	14.7	16	3	
2	-	[illegible]	—	3	" 100 "	17	"	14.9	"	3	
3	76	[illegible]	18°	3	action current not well defined	18	—	8.0	43	2½	
4	-	15.2	"	5		19	70	14.6	16	3½	
5	[illegible]	16.3	17	3	S.C. 110	20	—	"	20	3	
6	-	14.5	"	3	" 120	21	—	13.5	24	1	[illegible]
7	80	14.1	30	4		22	70	"	31	3	
8	-	14.0	34	3		23	—	6.8	44	3	[illegible]
9	80	"	37	3		24	70	13.7	17	3	
10	-	14.[illegible]	40	3½		25		"	18	3	
11	78	14.2	30	3½		26	66	15	"	3	[illegible]
12		14.7	17	3							[illegible]
13	-	14.[illegible]	40	3							[illegible]
14	74	14.[illegible]	16	3							
15	-	10.7	[illegible]	[illegible]							

Exp. Dec 20

[illegible] ; now for [illegible]

No	D	[illegible]	[illegible]	[illegible]	Remarks
1	43	[illegible]	[illegible]°	[illegible]	S.C. [illegible]
26	[illegible]	10.[illegible]	[illegible]	421	
27	–	17.0	16	2	
28	–	"	–	2	
29	–	10.0	46	2	
30	–	10.3	16	2	
31	20	9.8	"	2	S.C. 130
32	–	9.1	10	2	" 140
33	–	9.0	"	2	" 150
34		3.2	"	2	" 160
35	18	3.0	"	2	
36	–	"	"	2	
37		2.8	40	2	
38	–	2.4	41	2	

No	[illegible]	[illegible]	Temp	[illegible]	Remarks
39	–	2.8	42	2	
40	16	2.3	45	2	
41	—	2.3	15	2	
42		2.6	"	2	
43	–	2.5	"	2	
44	—	2.2	40	2	
46	13	2.0	45	4	26-47 tank supply 14-16°.
47	–	2.2	14	2	nerve in good condition

Exp. Jan 9, 1900

Nerve kept ; scissor-section ; nonpolar. electrodes quite isometric

no	[illegible]	d	temp	time	remarks	no	[illegible]	d	[illegible]	[illegible]
1	100	22.5	14°	h. m. 11.30	S.C. [illegible]	13	79	4.0	2[illegible]	3
						14		4.0	31	2½
9	–	24	16	12.1[illegible]		15	–	4.3	34	2½
10	–	25.2	7[illegible]	2		16	–	3.1	36	2
11	–	26.0	15	2		17	–	4.3	38	2
12	–	27.2	75	2		18		5.0	40	2
13		26.3	13	2	exp. discontinued until 8 pm	19	–	3.6	42	2
						20		4.5	45	2
1	138	25.2	–	2-56	fresh section; S.C. 100	21	–	[illegible]	18	2
6	102	3.3	16	3-10	S.C. 150	22	–	3.0	17	2
7	–	2.8	17	2		23	66	2.0	"	2
8		2.7	18	2		24		2.8	21	2
9	–	3.6	21	2		25		3.0	"	2
10	–	2.3	16	2		26		3.1	17	2
11		4.0	22	2		27	–	1.9	16	2
12	–	3.6	18	3		28	60	2.7	"	2

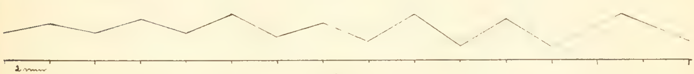
No.	[illegible]	[illegible]	Temp.	[illegible]	Remarks	No.	[illegible]	[illegible]	Temp.	[illegible]	Remarks
29	-	1.7	16	2	S.C. [illegible]	55	31	6.0	16	2	
30		4.2	40	2		56	—	5.6	41	2	
31	—	1.5	16	2		57	—	6.0	16	2	
32	-	7.0	4[illegible]	2		58	—	10.0	41	2	
33	—	1.5	16	2		59	—	[illegible]	16	2	
34	—	?	40	2		60	—	7.1	4[illegible]	2	
38	55	26.1	17	8	S.C. 1[illegible]	61	—	5.7	16	2	
39	-	28.3	"	2		62	—	7.6	[illegible]	2	
40	-	15.3	45	2		63	—	5.5	17	2	
41	—	27.3	16	2		64		1.0	42	2	
42	—	20.[illegible]	46	2		65		5.5	16	2	
43	-	27.[illegible]	17	[illegible]		66		10.0	44	[illegible]	
44	—	22.3	40	2		67	37	3.5[illegible]	1[illegible]	[illegible]	
45	—	21.2	46	2	5-45 tank supply [illegible]	68		2.9	17	2	
46	48	25.[illegible]	17	[illegible]		69	—	8.7	40	2	
						70	·	5.0	16	2	
52	—	11.8	16	12	S.C 140	71	31	24.5	"	2	S.C. 100
53	—	6.2	"	2	" 143	72		17.5	46	2	52-73 tank supply [illegible]
54	—	7.7	41	[illegible]		73		28.[illegible]	[illegible]	[illegible]	

At the end of this experiment (Jan. 7) the nerve was stiff between the tunnel and the lead-off electrodes.

The curves below are plotted from the foregoing experiment, observations 38 - 46 (1); 53 - 67 (2).

The decrease in the action current with a strong stimulus is shown when the temperature was raised from 17° to 45°; the increase with a weak stimulus when the temperature was [illegible] from 45° to 17°

1.
Decrease with strong stimulus



2.
Increase with weak stimulus

Exp. [illegible] 11

Nerve kept [illegible] non-polar. electrode 2.5 mm.

No	D	a	Temp.	Time	Remarks
				h. m.	
1	55	17(?)	15°	4-53	S.C over primary
2	53	3.3	"	2	" 160 mm.
3	52	2.0	"	2	
4	49	3.6	45	3	
5	—	4.0	46	1	
6	—	2.0(?)	18	1½	
7	-	1.7	"	2½	
8	—	3.6	45	2	
9	41	2.9	46	2	
10	—	2.+(?)	17	2	
11	—	3.0	40	2	
12	—	[illegible].0	17	2[illegible]	S.C over primary
13		0.[illegible]	50	2	
14	-	2.0	17	1	
15	—	3.5	"	½	
16	—	0.0	48	1½	1-17 tank supply 16 19°
17	—	0.0	17	2	nerve not dried

Exp. Jan 27

weak stimulation - low "basin" temperature

[illegible]

No	E	[illegible]	imp.	time	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	
1	79	25.7	—	h. m. 10 17	S.C. over primary	30	—	—	40	1	
2	—	0.5	18°	7	S.C = 180 m.m.	31	—	7.0	45	½ (?)	
3	—	0.5	43	[illegible]		32	—	[illegible]	11	1	
4	-	0.2	18	2	1-4 tank supply 18°	33	—	—	38	1	
						34	—	5.2	42	1	
19	—	8.7	10	h. m. 11-0	S.C. 150	35	60	4.2	11	2	
20	-	[illegible]	"	2		36			38	1	
21	-	3.0	"	1	S.C. 155	37	—	6.3	44	¾	
22	—	3.3	"	1		38	—	3.3	11	1¼	
23	-	9.5	"	1	S.C. 150	39	—	4.8	"	1	
24	-	2.1	"	1	" 155	40	—	2.5	"	1	
25	-	3.2	37	2	-	41	—	6.0	10	1	
26	—	2.7	10	2		42	—	3.0	9	1	19-42 tank supply [illegible]
27		—	38	1							
28		7.0	43	½							For additional remarks see next page
29	—	2.0	11	1½							

The experiment was continued until at the end the nerve had dried, but if we compare the values at [illegible] with 42 the [illegible] [illegible] altered.

[illegible] bent in ∩ shape was used; across this lay the nerve.

The following table gives the readings in m.m. of the action [illegible] being S.C = 155 m.m.

9 - 11°	37 - 45°
3.0	
3.3	
2.1	3.2
2.7	7.[illegible]
2.0	
3.4	7.0
4.2	5.2
3.3	6.[illegible]
4.8	
2.5	
6.0	
3.0	
[illegible].6	5.[illegible]

Exp. Feb 2

[illegible] scissor-section [illegible]

[illegible]

No	D	a	Temp	Time	Remarks	No	[illegible]	[illegible]	[illegible]	[illegible]	Remarks
1	66	15	21°	h m 3-35	S.C. 100 mm.	17	—	[illegible]	[illegible]	[illegible]	
4	—	19.2	"	6		18		1.0	17	1	
5	—	16.8	41	2		[illegible]	—	[illegible]	[illegible]	1	
6	—	15.0	42	1		20	·	5.2	[illegible]	[illegible]	
7	—	20.3	21	1		[illegible]	—	[illegible]	[illegible]	1	
8	—	6.7	"	1	S.C. 150	[illegible]		1.0	[illegible]	1	
9	—	"	"	1		[illegible]	·	5.2	41	2	4-24 tank supply 18·21
10	—	1.0	"	1	S.C. 155	24	—	1.1	18	2	experiment was continued: at end nerve [illegible]
11	—	1.9	20	2							
12	—	5.2	40	2							
13	—	3.5	20	1½							
14	48	4.7	"	2							
15	—	1.0	19	1	S.C. 157						
16	[illegible]	1.1	"	[illegible]							

It will be seen upon consulting the above protocols that, with a strong stimulus, i.e. a stimulus producing almost or quite a maximal galvanometric response, there is no increase in the action current as the temperature of the stretch b is raised. I have observed no change until the temperature is sufficient to cause a decrease. With a maximal stimulus this has been my universal experience, when the temperature of the stretches a and c was not far from room temperature. If we call the temperature which the whole nerve has before the changes in the temperature of the stretch b begin the "base line temperature", then it may be stated that, from a base line temperature between 15 and 25°C., there is

no increase in the action current called forth by a strong stimulus, when the nerve impulse has to pass through a heated area.

If the base-line temperature be as low as 10° C there may be an increase as the following experiment shows.

Jan 30.

Nerve kept; thermal section. Non-polarizable electrodes were quite isoelectric. Nerve lay across glass tube

no	D	a	temp	[illegible]	no	D	a	temp	[illegible]
1	61	14.3	13°	3-33	28	—	23.5	41	1
21	44(?)	15.5	9	4-2	29	—	19.5	9	1
22	—	18.3	"	1	30	—	22.4	41	1
23	—	22.8	41	1	31	—	18.3	9	1
24	—	20.7	10	1	32	—	21.3	41	1
25	—	23.1	41	1	33	—	16.8	9	1
26	—	20.6	9	1	34	44	--		$2\frac{1}{2}$
27	—	[illegible]	"	1					

In the above experiment the secondary coil was over the primary, but the arrangement of the inductorium must be considered; no iron core, Helmholtz modification ect. This stimulus was not more than the tip of the tongue could readily bear. From the 21st to the 34th observation the temperature slowly varied from [illegible]. At the end of the experiment the nerve was dried where it lay across the glass tube.

Two other experiments indicate the same thing. It may be that cooling the whole nerve down to 10° or somewhat lower so heightens its irritability that it then gives a greater action current when the impulse passes through a heated area.

Boruttau (14) has called attention to the beneficial effect of a moderately low temperature for the action current. I pre

sume that what is meant is the temperature to which the whole frame is exposed. He found on the other hand that warming caused a decrease in the action current. "There exists therefore a temperature optimum which in the case of the frog is quite low."

Some of my own experiments indicate the same thing. Perhaps had the base line temperature in my experiments been 10° C or lower, the results with strong stimuli might have been different. I would therefore emphasize the necessity of giving the temperature of all parts of the frame in such experiments as the ones under consideration, this the more particularly since there exists a contradiction in results which arises [illegible]

lack of so doing. Thus from Gotch and Macdonald[x] we have: "There is therefore no doubt that nerve is more readily excited by such stimuli as break-induced currents when warmed, and similar observations with the make induction currents showed the same favourable effect of warmth." This refers only to the case where the stimulated point is warmed, the rest of the nerve being at room temperature. Borutttau's statement refers to the temperature of the entire nerve, and falls into line with the observations upon cooled frogs, the heightened irritability of whose nerves is well recognized.

The following schema is intended to illustrate what has just been discussed. a is the stretch of nerve stimulated

[x] l.c. p. 270

while b is the rest of the room. The numbers under a and b are the temperatures which a and b are supposed to have in the five cases considered.

	a	b
1.	35	35
2.	35	20
3.	20	20
4.	10	20
5.	10	10

If one observer compares 4 and 2 with 3, the other, and 5 with 3, they would come to opposite conclusions, viz; warmth favorable, cold favorable. This contra-

diction would be due to the fact that they had not been explicit enough in the statement of the conditions of their experiments. We suppose of course that, in the experiments indicated by the above scheme, changes in electrical conductivity, more especially when the temperature is raised, are compensated for.

If we designate by weak stimulus a stimulus that calls forth but a small fraction of the maximal galvanometric response, and by moderate stimulus one between this strength and the maximum, we may apply what has been said about the response to the strong stimulus to the response obtained upon stimulating with a moderate stimulus, i.e. there is no increase,

So far the results agree with those obtained in the spring of 1899.

With a weak stimulus I have observed a very few cases of an increase; where the increase was most pronounced the action current that showed it was but a small fraction of the maximal response e.g. $\frac{1}{7}$ - $\frac{1}{20}$. These four positive experiments are to be found among the reported experiments: Jan. 7, Jan. 11 (?), Jan. 27, Feb. 2.

On the other hand there are 15 experiments, in which the response was $\frac{1}{3}$ to less of the maximal, that showed no increase. The results are therefore in the main negative. Out of 67 experiments which make up this division and in which all strengths of stimulus were employed from minimal to

maximal there are only, as mentioned, three or four which are quite positive.

We are therefore justified in saying that the increase which the nerve impulse suffers upon passing through a heated stretch is difficult to demonstrate with the galvanometer.

I call especial attention to the experiment under date of Jan 9, where especially with rise of temperature of the stretch to the action current increased. It is also worthy of note that in this experiment the results obtained with a strong stimulus are clearly contrasted with those gotten with a weak stimulus. With the strong stimulus the action current decreases when the high temperature is reached; with the weak stimulus it is increased. The other experiments show

the same phenomenon.

I subjoin the following experiment to show a difference in the result obtained when using a strong and a weak stimulus, the whole nerve being at the same temperature - room temperature. The experiment was primarily performed to determine the effect of reversing the poles of the secondary coil of the inductorium, my attention having been called to this point by a communication from Radzikowski, who claims that the presence of electrotonic currents can thus be detected; for if such are present there will be an inequality in the action currents obtained from the two directions of current.

As in all the experiments of this division, the iron core of the primary coil was removed.

the Helmholtz modification was employed and the primary circuit – fed by one storage-cell – contained 3 ohms, resistance enough to render the play of the hammer regular. The action current is given first with one direction of the induced current, then with the other. Under I the series of breaks was ascending; under II the breaks were descending. The stimulated stretch = 2 m.m.; the intermediate stretch = 4 m.m.; the led-off stretch = 5 (?) m.m. The stimulus was applied at 2 min. intervals except in two instances where the interval was [illegible] 3 min. respectively. At the end of the experiment the intermediate stretch of nerve was crushed; there was no response from the nerve upon stimulating, the secondary coil being shoved over primary.

Apr. 5

Reversal of poles of the [illegible]

Large nerve, [illegible], thermal section.

a				[illegible]				[illegible]			
D	I	II	S.C	D	I	II	S.C	D	I	II	S.C
[illegible]	17.5		[illegible]	75		[illegible]				[illegible]	
		12.[illegible]			[illegible]				[illegible]		[illegible]
	15.[illegible]					12.2	[illegible]			[illegible]	
		13.1			[illegible]				[illegible]		
	15.2					12.3				12.3	
80	11.5		120	72	12.3				14.0		
		11.5				12.2		63		3.9	150
	11.7			70	3.4		150		2.8		
		11.8				3.9				3.9	
	11.8				3.3				3.0		
76		11.5				4.0			3.1		
	14.7		110		2.8			59		3.0	
		12.7				3.9				3.4	
	14.9			65	2.7						

	a		
D	I	II	S.C
	10.2		0
		11.5	
	11.5		
		11.9	
59	11.2		100
		11.3	
	12.4		
		11.8	

The arrangement which calls forth the greatest response at 100 m.m. distance becomes the less effective arrangement at 150 m.m. This is but one experiment; I cite it merely to show that there may exist a qualitative difference in the various strengths of the stimulating current.

The result of these experiments at

first sight does not argue for the view that the action current may be taken as a true measure of physiological activity; for it is very easy to show that passing the nerve impulse through a [illegible] area [illegible] with increase of maximal muscle contraction to a minimum. This has already been mentioned, and I have repeatedly verified it [illegible] with the galvanometer. However, the increase seems to be very difficult to obtain with any but a weak stimulus and by no means everytime with that.

If we consider the curve which expresses the relation between the strength of stimulus and the resulting action current (Waller 16, Greene 17), we are struck by the great extent of the curve which

lies wholly out of the range of functional impulses. The strength of stimulus necessary to call forth a minimal [illegible] the contraction lies far below that necessary for a maximal action current; that is, the action current that corresponds to the minimal muscle contraction is but a fraction of the maximal action current.

If we assume that the nerve impulse, when it passes through a region of higher temperature, is affected only within the range of functional activity, the results obtained with the [illegible] [illegible]. [illegible] aside the question of a low base-line temperature, considering only the case where it lies between 15 - 25° C; under such [illegible]

serve as [illegible] increase in the action current. But if the above assumption is correct, we should expect [illegible] the action current itself a function of impulse, i.e. of the [illegible] normally [illegible] in the nerve. In the case of the kept nerve the action current is considerably greater than that of the fresh nerve, and in such case a small fraction of the maximal action current may represent, so to speak, a normal impulse – one of the intensity that is conducted along a nerve when the muscle is thrown into activity.

I performed a few experiments to determine the [illegible] [illegible] [illegible] ometric. It was found that, using

tetanic stimulation, the [illegible] is [illegible] called into activity at about 200 m.m. distance, such a stimulus giving no action current; at 150 m.m. the response was full tetanus, while at this distance the action current was but a few millimeters comp. Steinach 18, Boruttau 19, Biedermann 20, for similar results; Waller[1] for the opposite). The nerve is capable of increasing its response with increasing stimuli far beyond the muscle, the muscle having reached its maximal response, when the nerve, as it were, has just begun.

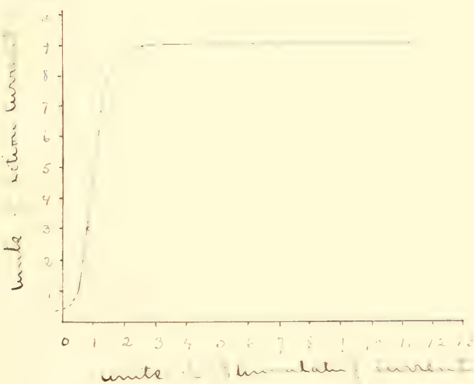
Within the range of functional activity there can be little question as to the increase which the nerve im[illegible] when it passes through an area of higher temperature. This

[1] l.c.

is made most highly probable à priori from the fact that, under favorable conditions warming, a nerve may excite with a tetanic contraction. If heat can thus act as a stimulus we should expect that an area of nerve whose temperature had been raised would be more responsive to an inflowing stimulus than the neighboring cooler portions. [illegible] the [illegible] the nervous response is governed by a different law of disassimilation in Hering's (21) sense, then an increase in temperature may [illegible] temperatures.

[illegible] Greene has confirmed his results in the case of mammalian nerve [illegible] that the beginning of the

energy curve for nerve is at first convex to the abscissa line, followed by a long, straight portion, this straight ascending limb is succeeded, as shown by [illegible] by a straight horizontal [illegible] parallel to the abscissa axis.



The accompanying curve is modified from Greene's. The units are minute fractions [illegible]

action current being about $\frac{1}{500}$ that of the stimulating current.

These [illegible] the [illegible] response fairly well into on the straight ascending portion, but I take it that this response was for single break shocks; for tetanic stimulation it would lie considerably lower. If this initial convex portion and the beginning of the straight limb represent the range of functional activity, we see indeed that it is subject to a different law of disassimilation, and this can possibly account for the negative results obtained.

[illegible] muscular response when we allow the nerve impulse to pass through an area of warmed nerve, we are not perhaps justified in expecting the same from the galvanom-

eter, unless the instrument is capable of showing a deflection at a strength of stimulus which just calls the muscle into activity.

According to my experiments there is no doubt that, from a base-line temperature of 15°-25°C there is no increase in the action current when the impulse has to pass through a cooled area, if the stimulus lies above what I have designated as a weak one.

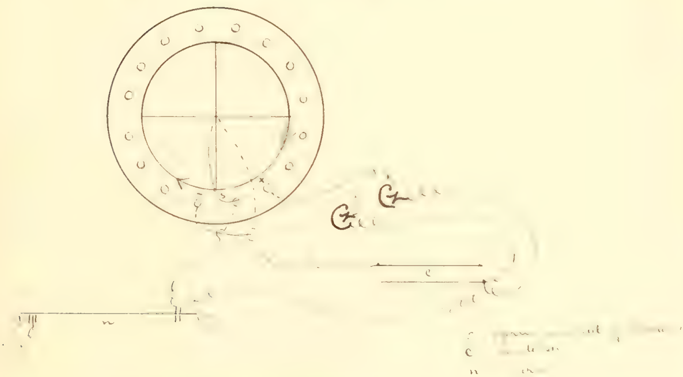
2. Stimulation by Condenser-discharge.

Apparatus — method — results

In these experiments the apparatus, with the exception of that part of it which delivered the stimulus differed very little from the apparatus of the preceding division. The ∩-shaped glass tube was used instead of the burette.

In order to avoid polarization two cells were employed in connection with the condenser; they were so arranged that they charged the condenser first + − then − +. To secure a tetanic stimulation the Bernstein rheotome was modified in the following way; — An ebonite disc was brought below the revolving wheels of the rheotome; in this disc were 16 brass plugs, every other brass plug put the two holes of the

condenser into connection through the wire, the intervening flange charged the conden- ser; and they were so connected with the [illegible] of the [illegible] that it [illegible] [illegible] itself at [illegible] ing plug. The revolving wheel carried a platinum wire bent into a spring which swept over the flanges, thus alternately establishing contact with each plug. The arrangement is made clear by the following scheme.



Each revolution of the wheel thus caused 8 discharges through the nerve, each succeeding discharge being opposite to that which just preceded. The rheotome was driven by the Helmholtz motor, the movable coils of which were fed by two storage cells in parallel, the fixed coils being connected with one Edison-Lalande cell; thus supplied, with the governor screwed up, the motor ran well and smoothly.

Not many experiments were performed with this stimulus because of the difficulty of obtaining frogs of good size just at the time when these preliminary experiments were made. They number six in all, of which the following may serve as examples;

Feb. 16

Con[illegible] [illegible] 24

Nerve kept (?). 2 Edison-Lalande cells charged the conden[illegible]

[illegible] + - , [illegible] + , voltage [illegible]

ured by Weston voltmeter = 3/4 volt. Capacity of condenser = 0.5 mf

n	D	[illegible]	[illegible]	[illegible]	Remarks	no	[illegible]	[illegible]	[illegible]	[illegible]	Remarks
1	77	4.[illegible]	[illegible]	[illegible]		15	—	[illegible]	[illegible]	2	
2	—	5.5	2[illegible]	[illegible]		16	—	"	20	2	
3	—	5.3	[illegible]2	[illegible]		17	—	"	"	[illegible]	
4	—	[illegible]	2	[illegible]		18	—	5.7	37	1½	
5	—	6.[illegible]	"	2		19	—	5.[illegible]	[illegible]	1	
6	—	6.5	"	1		20	—	[illegible]	17	1½	
7	—	6.[illegible]	"	[illegible]		21	[illegible]	5.7	"	[illegible]	
8	—	6.7	"	[illegible]		22	—	[illegible]	40	1½	
9	—	6.5	2[illegible]	[illegible]		23	—	5.7	4[illegible]	1	
10	—	[illegible]	"	1		24	—	6.0	17	1½	
11	76	[illegible]	"	[illegible]		25	—	[illegible]	[illegible]	1½	
12	—	5.6	25	2		26	—	4.7	45	1	2-27 tank supply 23-26°; for 1½ min at 22,28°
13	—	5.9	4	2		27	—	6.3	20[illegible]	1	
14	—	[illegible]	[illegible]	[illegible]							

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	5.5	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	12.5	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

Feb 23

Nerve cut out 2 hrs. thermal section. 2 storage cells charg(?) the condenser + -, - +; voltage = 2; capacity of condenser 0.5 m.f.(?)

No	D	a	Temp.	Time	Remarks	No	D	a	Temp.	Time	Remarks
1	51	3.5	[illegible]	[illegible]		17	—	[illegible]	[illegible]	1	
2	—	4.0	"	1		18	—	3.3	35	1	
3	—	4.1	"	1		19	—	2.7	39	1	
4	—	"	"	1		20	—	3.1	21	1	
5	—	3.2	35	1		21	—	3.2	"	1	
6	—	"	36	1		22	51	2.9	21	2	Between 22 and 23 nerve was moistened; had become a little stiff and it lay over.
7	—	3.4	20	1		23	—	3.2	"	3	
8	—	3.6	"	1		24	—	3.6	"	1	
9	—	4.0	"	1		25	—	3.7	"	1	
10	—	4.2	"	1		26	—	3.2	32	1	
11	—	4.0	34	1		27	—	3.0	35	1	
12	—	3.8	20	1		28	—	2.7	42	1	
13	—	4.1	"	2		29	—	3.6	21	1	
14	—	4.0	33	1½		30	—	3.5	"	1	
15	—	2.8	42	1½		31	—	3.0	34	1	Temp. rose to 37° at first
16	—	[illegible]	[illegible]	1		32		[illegible]	"		

No.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	–	[illegible].0	3[illegible]	[illegible]	
[illegible]	–	[illegible]	41	1	
35	–	[illegible]	[illegible]	1	
[illegible]	–	[illegible]	3[illegible]	[illegible]	
[illegible]	–	[illegible]6	[illegible]	1	
4[illegible]	–	[illegible]	"	1[illegible]	
41	41	"	"	$2\frac{1}{2}$	
44	–	3.2	39	3	
45	–	2.8	41	1	1–47 tank supply 20–21°; at base to 25°
47	–	3.4	20	2	nerve was not dried

From the foregoing experiment under date of Feb. 16 it is seen that the effect of cooling the stretch b down to near zero is nil, the action current seeming to suffer no decrease whatsoever. This was the general result of these experiments when the response to the series of condenser dis-

change was seen during the time the maximal response obtained when stimulating with induced currents. On the other hand, when the action current from the condenser discharge fell but little below that called forth by secondary coil distance 100 m.m., there was a decrease in the action current when the temperature of the stretch was fell to near zero.

In order to determine whether when faradic stimulation was used, a weak stimulus would also be little affected by low temperatures, I performed the following experiment which shows very distinctly that the action current resulting from the weak stimulus is not at all affected.

Fb 16

Nerve kept, thermal section; stretch to [illegible] glass tube; non-polarizable electrodes, [illegible]

1	12	[illegible]	[illegible]	[illegible]	[illegible]	20		4.[illegible]			
[illegible]		6		[illegible]		[illegible]		[illegible]	1[illegible]		
[illegible]		11	4	2		[illegible]		[illegible]	"	1	
4		"	"	1		[illegible]	—	[illegible]	"		[illegible]5
5		[illegible]	2			[illegible]		[illegible].5		1	[illegible]1.0
6		16.[illegible]	[illegible]	2		2[illegible]		1[illegible]	[illegible]		[illegible]0
7		16.[illegible]	"	2		[illegible]6		[illegible]			[illegible]
8	1[illegible]	[illegible]5.5	[illegible]	2	[illegible]	27		[illegible]		1	
9		[illegible]	26	2					"		
1[illegible]		8.[illegible]	2	[illegible]				5.[illegible]			"
[illegible]		[illegible]	16	2		[illegible]0					[illegible]0
1[illegible]	8[illegible]	[illegible]		22	[illegible]C 130						[illegible]0
15		1.5	"	[illegible]			-	6.[illegible]			[illegible]0
1[illegible]		8.[illegible]						5.[illegible]	"		
1[illegible]		6.[illegible]			[illegible]C	34		[illegible]	1[illegible]		
1[illegible]		4.0						1[illegible]	"		

n.	[illegible]	u	[illegible]	[illegible]	s
36	—	3.5	17	1	S.C. 160
[illegible]		4.[illegible]	"	1	
3[illegible]	–	5.[illegible]	2[illegible]	[illegible]	
39	—	4.0	"	1	
40	—	6.0	"	1	
41	—	4.3	"	1	
42	—	5.9	"	1	
43	—	3.0	17	1	
44	—	6.5	"	1	
45	—	4.3	"	1	1-46 tank supply 22–26°
46	78	14.8	18	$1\frac{1}{2}$	S.C. 120

Wh[illegible] the temperature [illegible] was [illegible] no increase was observed, but uniformily a decrease when the tempera-ture approached 40°C. [illegible] the case of the two experiments reported even 35°C appears to cause a decrease. In these experi-

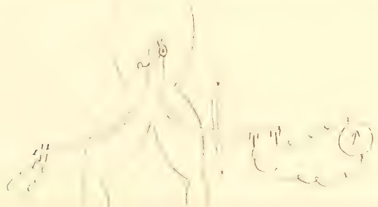
ments the nerve lay across a thin walled glass tube, so that the temperatures were not so high as when the tunnel was employed.

It would seem from our results from these half dozen experiments, that the galvanometric response is affected in the same way whether the stimulus be started by condenser discharges or induced currents, when the nerve impulse passes through a cooled or heated area, except in so far that no increase of the action current with weak stimulus was noticed in the case of the condenser discharges. But in these experiments no such small fraction of the maximal action current was used as in the previous division.

3. Reflex stimulation

method and results

Since the fever with marked increase in the action current had been observed in the case [illegible] Dr. [illegible] suggested that I try to get a negative variation upon reflex stimulation and then to interpose a warming tube between the [illegible] electrodes [illegible] the galvanometer. With such an arrangement [illegible] negative variation [illegible] increase



About a dozen experiments were performed, but only 3 or 4 gave any results at all, and these were negative as far as any increase in the action current was concerned. The first lot of frogs used were of medium size, and were [illegible] by the [illegible] of the [illegible]. They were either curarized or had their brains [illegible]; in the latter case they were pinned out upon a cork board to prevent any movement of the nerve on the electrodes. No negative variation was obtained from this first set of experiments.

We received in the laboratory about the first of April a new lot of frogs, there being among these five very large and vigorous ones. They were cooled after the manner recommended by Steinach 22 in order to get the most favorable specimens. They were allowed to remain in the ice chest for

[illegible], and the [illegible] before the experiment they were [illegible] on the ice. Three of these were curarized, two were etherized during the preparation of the sciatics and then allowed to come out of the anaesthesia.

In the first experiment performed the skin over the thigh was stimulated by induction shocks; in the others one sciatic was stimulated, the other was connected with the galvanometer. [illegible] in all but the first experiment; it was small, only a fraction of a millimeter [illegible]. In the first experiment a deflection of as much as 9 mm was observed, there being a complete return of the image to its initial position. In this experiment however the frog was not curarized and [illegible]

-fiction might have been due to some movement of the frog against the [illegible] for it was difficult to so securely tie the frog down as to prevent all movement.

Summary

We may summarize the results as follows:

Confirmatory of the results of Boruttau and Fröhlich, the action current can, like the muscle contraction upon indirect stimulation, be blocked out by the application of heat or cold to the nerve with a more or less complete return, if the high or low temperature be not too long maintained; and this whether the temperature block be applied at the point stimulated or between this and the led-off stretch.

Under conditions where a minimal muscle contraction will be increased to a maximal, when the nerve impulse passes through a heated area, no increase in the action current is to be observed with

a galvanometer of the sensitivity of the one used in these experiments, unless the action current of the excitation is but a small fraction of the maximal one, and with this [illegible] [illegible] an increase is the exception.

The nerve impulse seems to be similarly affected whether it be aroused by the induced current or the [illegible] [illegible] when it passes through an area of higher or lower temperature, so far as can be judged by the galvanometric method.

As far as the experiments go, the action current obtained [illegible] [illegible] increase when the nerve impulse, set up normally by the nerve cells, passes through a heated stretch.

The general result of the experiments is another instance of the fact that the

galvanometer is by no means so sensitive an indicator of the nerve impulse as the muscle. The action current ordinarily studied and described lies far beyond that produced by maximal functional impulses, and though a perceptible [illegible] is produced only upon direct stimulation of the nerve fibre.

It is a pleasant duty to acknowledge my indebtedness to Prof. Howell, and to thank him for his kindly advice and encouragement given during the progress of the investigation.

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Vita

I, Joseph Caudell Herrick, was born at Shelbyville, Illinois on the 6th of May 1894. After having spent nine years in the public schools of my native town, I entered the Virginia Military Institute at Lexington Va., where I remained for two years. In September 1913 I became a matriculate of the University of Virginia and was graduated as B.A. from that institution three years later. During the academic year of 1916-17 I held the position of instructor in biology which I resigned at the end of the session to enter the Johns Hopkins University. In this university I have followed courses in animal physiology, chemistry and physics; holding during the present session the fel-

Coworkers in animal physiology